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DYNAMIC FOUNDATION INVESTIGATION FOR MMW RADAR FACILITY, ROI-NAMUR KWAJALEIN ATOLL, MARSHALL ISLANDS

by

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Final Report

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Surface refraction and vibratory seismic investigations were performed at the proposed location of the MMW radar facility on Roi-Namur Island, Kwajalein Atoll, Marshall Islands, for the purpose of determining Young's moduli, Poisson's ratio, and shear moduli as functions of depth for foundation materials at this site. These elastic properties are necessary for the design of foundations that require a high degree of stability under dynamic loading conditions. Foundation materials encountered at this site (Continued)

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20. Abstract (Continued)

consist of loose coral sands and topsoil silts to a depth of 7 ft, which are underlain by medium to dense coral sands that extend to depths of at least 75 ft. Occasional coral heads and cemented lenses were also encountered in this area.

Results of the investigations indicated that the shear modulus increased from about 5,000 psi near the surface to 20,000 psi at a depth of 28 ft. Young's modulus was about three times greater than the shear modulus for a given depth. Poisson's ratio averaged 0.34 from a 0- to 4.5-ft depth and 0.49 below 4.5 ft.

In addition to the foundation tests, ground motion measurements were made at the MMW site in an attempt to ascertain amplitudes caused by operation of existing radar facilities in proximity to the site. The largest particle velocity measured was 0.003 ips.

Preface

The foundation investigation for the MMW Radar Antenna Project was authorized by the U. S. Army Engineer Division, Pacific Ocean (POD), Honolulu, Hawaii, in IAO No. PODSP-MIL-80-19, dated 14 February 1980.

The field investigation was conducted during the period 7-15 March 1980 by Messrs. R. E. Wahl and J. L. Llopis of the Field Investigations Group (FIG), Earthquake Engineering and Geophysics Division (EEGD), Geotechnical Laboratory (GL), U. S. Army Engineer Waterways Experiment Station (WES). The analysis of the data obtained was performed by Messrs. Wahl and Llopis, under the general supervision of Mr. R. F. Ballard, Jr., Chief, FIG; Dr. W. F. Marcuson, III, Acting Chief, EEGD; Dr. D. C. Banks, Acting Chief, GL; and Dr. P. F. Hadala, Assistant Chief, GL. The report was written by Messrs. Wahl and Llopis.

COL Nelson P. Conover, CE, was Commander and Director of the WES during the performance of this investigation and preparation of this report. Mr. Fred R. Brown was Technical Director.

Contents

Conversion Factors, U. S. Customary to Metric (SI) Units of Measurement

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
feet per second	0.3048	metres per second
feet per second squared	0.3048	metres per second squared
inches	25.4	millimetres
inches per second	25.4	millimetres per second
pounds (force) per square inch	6894.757	pascals
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
slugs (mass) per cubic foot	515.3788	kilograms per cubic metre

DYNAMIC FOUNDATION INVESTIGATION FOR MMW RADAR FACILITY, ROI-NAMUR, KWAJALEIN ATOLL, MARSHALL ISLANDS

Introduction

1. The dynamic foundation tests described herein were performed at the proposed location of the MMW radar facility on Roi-Namur Island, Kwajalein Atoll, Marshall Islands. Exploratory borings were furnished by the U. S. Army Engineer District, Honolulu, to provide information on the subsurface conditions. The purpose of the field investigation was to obtain data on the stiffness of the foundation materials at this site as quantified by the elastic constants appropriate for small dynamic stress increments. Specifically, compression- and Rayleigh-wave (P- and R-wave) velocities were determined from which Young's moduli (E), Poisson's ratios (ν), and shear moduli (G) were calculated. These data are necessary for the design of foundations that require a high degree of stability under dynamic loading conditions.* In addition to the foundation tests, ground motion measurements were conducted at the MMW site in an attempt to ascertain amplitudes caused by operation of existing radar facilities in proximity to the site.

The Investigation

Location and description of test sites

2. The proposed MMW radar antenna site is located on Roi-Namur Island, Kwajalein Atoll, Marshall Islands, more specifically at an azimuth of 210 deg and a distance of 600 ft** from the existing TRADEX facility (Figure 1). The site can be characterized by fairly level terrain with palm groves, bushes, and a garden plot (Figure 2).

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* Department of the Army, Office, Chief of Engineers. 196[illegible]. Engineering and Design, Foundations Subject to Vibratory Loads, EM 1110-[illegible], Washington, D. C.

** A table of factors for converting U. S. customary to metric (SI) units of measurement is presented on page [illegible].

3. Boring data indicate that the soil at this site consists of loose coral sands and topsoil silts in the upper 7 ft, which are underlain by medium to dense uniform coral sands extending to depths of at least 75 ft. At the time of this investigation, the water table was approximately 6 ft below ground surface. Occasional coral heads and cemented lenses were also encountered in this area.

Test methods and calculations

4. The primary dynamic investigations were conducted in two phases: surface refraction seismic and vibratory tests. Each type of test was designed to reveal specific information relative to the physical properties of the MMW foundation materials.

5. Surface refraction seismic tests.* Four refraction seismic tests were conducted to determine P-wave velocities of the subsurface materials. These velocities were used in conjunction with R-wave velocities (analogous to shear-wave (S-wave) velocities) to determine Poisson's ratios. Data obtained from these tests consisted of time required for a P-wave to travel from initiation at a seismic source (sledgehammer impact) to points of measurement (vertically oriented geophones spaced at 10-ft intervals). Travel times were picked to the nearest 1/2 msec. Data are plotted in graphic form as distance versus travel time. The slope of the lines drawn to connect the plotted points indicates the velocity of the P-wave through each subsurface medium encountered. A change in the slope of the lines indicates that the wave has passed through an interface between two subsurface layers having different velocities. The depth below the surface at which the interface occurs can be calculated by means of the following equation:

$$Z_1 = \frac{x_1}{2}\sqrt{\frac{V_{c2} - V_{c1}}{V_{c2} + V_{c1}}} \qquad (1)$$

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* Department of the Army, Office, Chief of Engineers. 1979. Geophysical Exploration, EM 1110-1-1802, Washington, D. C.

where

D_1 = depth from surface to first interface, ft

x_1 = distance from seismic source to point at which first change in slope occurs, ft

v_{c1} = P-wave velocity in first layer, fps

v_{c2} = P-wave velocity in second layer, fps

6. Surface vibratory tests. Vibratory tests were conducted to determine the velocity of surface R-waves generated by a vibrator at controlled frequencies (EM 1110-1-1802). From this information, shear modulus can be determined.

7. The tests were performed by positioning the vibrator at a selected location and placing geophones in a straight line (starting at and extending away from the vibrator) at selected intervals along the surface of the ground. In this application the vibrator has a 50-lb force level within the frequency range of 15-300 Hz. The force level drops sharply at frequencies outside of this range. The vibrator was then operated at discrete selected frequencies with the surface R-wave being monitored by the transducers (geophone nearest the vibrator served as zero time). The time lag, referenced to the zero time geophone, is determined and plotted versus the respective distances that the geophones were from the vibrator. The R-wave velocity for the source frequency is determined from the slope of the line obtained in the plot. When the frequency and the R-wave velocity are known, a corresponding wavelength can be expressed as

$$\lambda = \frac{v}{f} \qquad (2)$$

where

v = wave velocity, fps

λ = wavelength, ft

f = frequency of vibration, Hz

The depth of penetration of the R-wave is assumed to be equal to one-half the computed wavelength.

8. <u>Computation of shear modulus, Poisson's ratio, and Young's modulus</u>. Wave velocity is dependent upon the ratio of the elasticity of the medium to its mass density, ρ, and wave type. The relation between shear modulus, G, and S-wave velocity, v_s, is

$$G = v_s^2 \rho \tag{3}$$

where

G = shear modulus, psi

v_s = S-wave velocity, fps

ρ = mass density of soil, γ/g, slugs/ft^3

γ = wet unit weight of soil, pcf

g = acceleration due to gravity, ft/sec^2

Based on WES experience, variations in G apparently correlate best with conventional methods when it is assumed that the depth for the computed value of G is one-half the length of the surface wave. Therefore, the computed value of G is considered to be shear moduli at such a depth.

9. The S- and R-wave velocities are related by Poisson's ratio. For Poisson's ratios ranging from 0.2 to 0.5, the difference in these velocities is less than 9 percent. Therefore, for practical purposes, S-waves can be considered to have the same velocity as R-waves. Thus, S-wave velocities can be determined by the vibratory tests described, and shear moduli can be calculated by use of Equation 3.

10. With the assumption that P- and S-wave velocities were determined for comparable materials, Poisson's ratio, ν, can be calculated from the ratio of these velocities, v_r (EM 1110-[illegible]):

$$v_r = \frac{v_p}{v_s}$$

Then

$$\nu = \frac{v_r^2 - 2}{2(v_r^2 - 1)}$$

11. The Young's modulus, E , can be determined by

$$E = 2(1+\nu)G \tag{6}$$

For design purposes, it is suggested that the values of G , ν , and E be selected as those determined for the depth at which the overburden pressure is equal to the static surcharge pressure of the proposed structure as described in EM 1110-345-310.

Analysis and Discussion of Tests Results

Surface refraction seismic tests

12. Four refraction seismic lines (R-1 through R-4) were run at the MMW site in the locations shown in Figure 2. Test data from these lines were plotted as travel time versus distance (Figures 3-6). Each test revealed a two-layer system. The P-wave velocity of the near-surface materials showed a degree of variability with velocities ranging from 800 to 1600 fps. Depths varied from 2.8 to 7.1 ft below the ground surface. The average velocity of these materials is 1100 fps and extends to an average depth of about 4.5 ft. This layer correlates with "fill coral," topsoil silts, and loose coral sands, which were revealed from borings located within the foundation ring.

13. The second layer appears to correlate with medium-dense to dense coral sands and gravels, which are "slightly" to "moderately" cemented. This layer showed a very uniform P-wave velocity distribution with true velocities ranging from 5400 to 5850 fps and averaging 5650 fps.

Surface vibratory tests

14. Eight vibratory lines (V-1 through V-8) were run in the locations shown in Figure [illegible]. The lines were positioned to provide adequate [illegible] for the foundation materials situated beneath the proposed [illegible] ring footing of the MMW radar antenna. Raw data quality was [illegible] and the velocities measured showed normal statistical scatter. Figure [illegible] [illegible]-wave velocity versus depth (wavelength [illegible]) data [illegible] [illegible] The [illegible]-wave [illegible] in the [illegible]

of material ranged from 560 to 850 fps. For depths between 4.5 and 28 ft, S-wave velocities ranged from 670 to 1000 fps.

Computation of Poisson's ratio

15. For the near-surface layer, the P-wave velocity (1600 fps) measured at the north end of line R-2 (Figure 4) was used for the computation of Poisson's ratio because these data were collected within the foundation ring. The results of this test show this velocity to be applicable to a depth of 7 ft. The S-wave velocity used in this calculation was obtained from lines V-1, V-2, V-3, and V-4 (which were also positioned within the confines of the ring), by averaging all velocities that penetrated to depths of 7 ft or less. The average was 795 fps. Using Equations 4 and 5, Poisson's ratio for the near-surface materials was computed to be 0.34.

16. The computation of Poisson's ratio for the second layer was made using the P-wave velocity of 5650 fps, which was the average true velocity of all refraction lines for this layer. The S-wave velocity used was the average of all velocities penetrating below 7 ft for vibratory lines V-1 through V-4 (within the ring) and below 4.5 ft for lines V-5 through V-8. The average S-wave velocity was 850 fps. Poisson's ratio (using Equations 4 and 5) was calculated to have a value of 0.49 for this layer.

Computation of elastic moduli, E and G

17. Equations 3 and 6 and a wet unit weight of 110 pcf* were used to compute shear and Young's moduli for the foundation materials. The values were then plotted versus the approximate depth (Figure 8). Also presented in this figure are laboratory soil classifications, field descriptions, and blow counts for the upper 35 ft of the 77-ft-deep boring B-3. Test results show that the shear modulus increases from about 5,000 psi at a 1-ft depth to 20,000 psi at 28 ft. Young's modulus varies from 12,000 psi at a 1-ft depth to nearly 59,000 psi at [illegible]. [illegible] of Young's modulus is approximately three times the value [illegible]

* Data provided by POD.

shear modulus for a given depth. These curves agree favorably with the data collected in 1966 by Ballard and Casagrande* for the ALTAIR Antenna site also located on Roi-Namur.

18. Since the quality of vibratory data was good and the subsurface condition of the second layer appears uniform to a depth of 75 ft, it is believed these moduli curves could be extrapolated to greater depths should the need arise.

Ground motion measurements

19. Measurements were made of ground motions at the MMW site with the existing radar facilities, ALTAIR and TRADEX, in operation. These facilities are about 900 and 600 ft, respectively, from the site. Ground motions (vertical particle velocities) were measured using a vertical geophone and an oscilloscope. The maximum peak-to-peak particle velocities measured were 0.003 ips when the antennas were rotating. The frequency of vibration was not measured. However, after the antennas stopped rotating, the velocity amplitudes at about this level were also observed. Since there was a significant amount of activity in this area from vehicular traffic, power tools, and workmen, the motions caused by ALTAIR and TRADEX apparently fall below 0.003 ips.

Conclusions

20. Surface refraction data collected at the MMW radar site revealed a two-layer velocity system. The P-wave velocity of the near-surface layer averaged 1100 fps and extended from ground surface to an average depth of 4.5 ft. The second layer had an average true velocity of 5650 fps and extended to undetermined depths. Vibratory test data showed that the shear modulus increased from about 5,000 psi near the surface to a value of 20,000 psi at 28 ft. Young's modulus was about

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* R. F. Ballard and D. R. Casagrande. 1966. "Dynamic Foundation Investigation, Roi-Namur, Kwajalein Atoll, Marshall Islands," Miscellaneous Paper 4-858, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

three times greater than the shear modulus for a given depth. Poisson's ratio averaged 0.34 from a 0- to 5-ft depth and 0.49 below 4.5 ft.

21. Measurements of ground motion were made at the MMW site in an attempt to see if they were induced by the ALTAIR and TRADEX radar facilities. The largest peak-to-peak particle velocity measured was 0.003 ips. Since this magnitude was observed with and without the antenna rotating, it is concluded that ground motions produced by the ALTAIR and TRADEX facilities fall below this value.

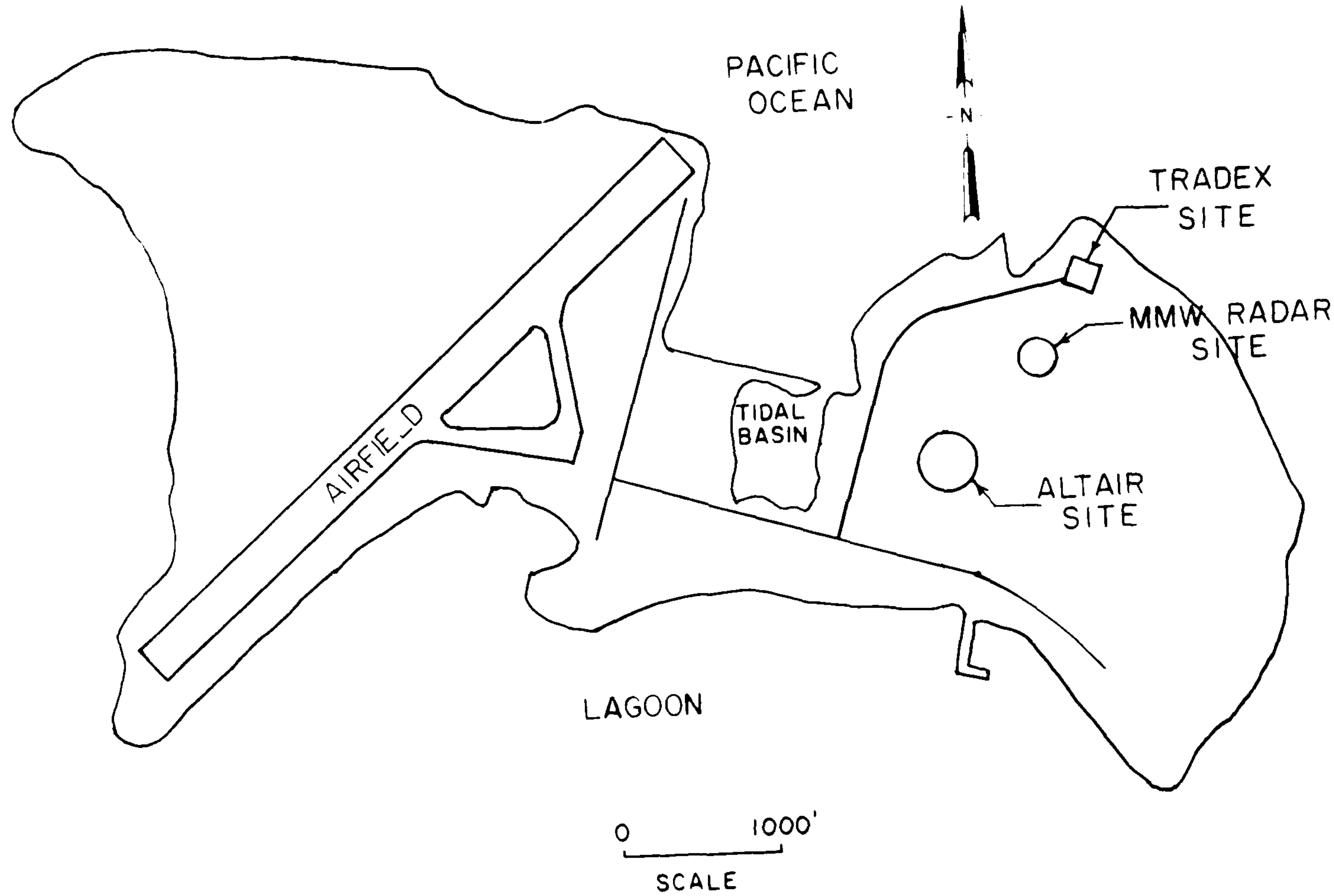

Figure 1. Site location map

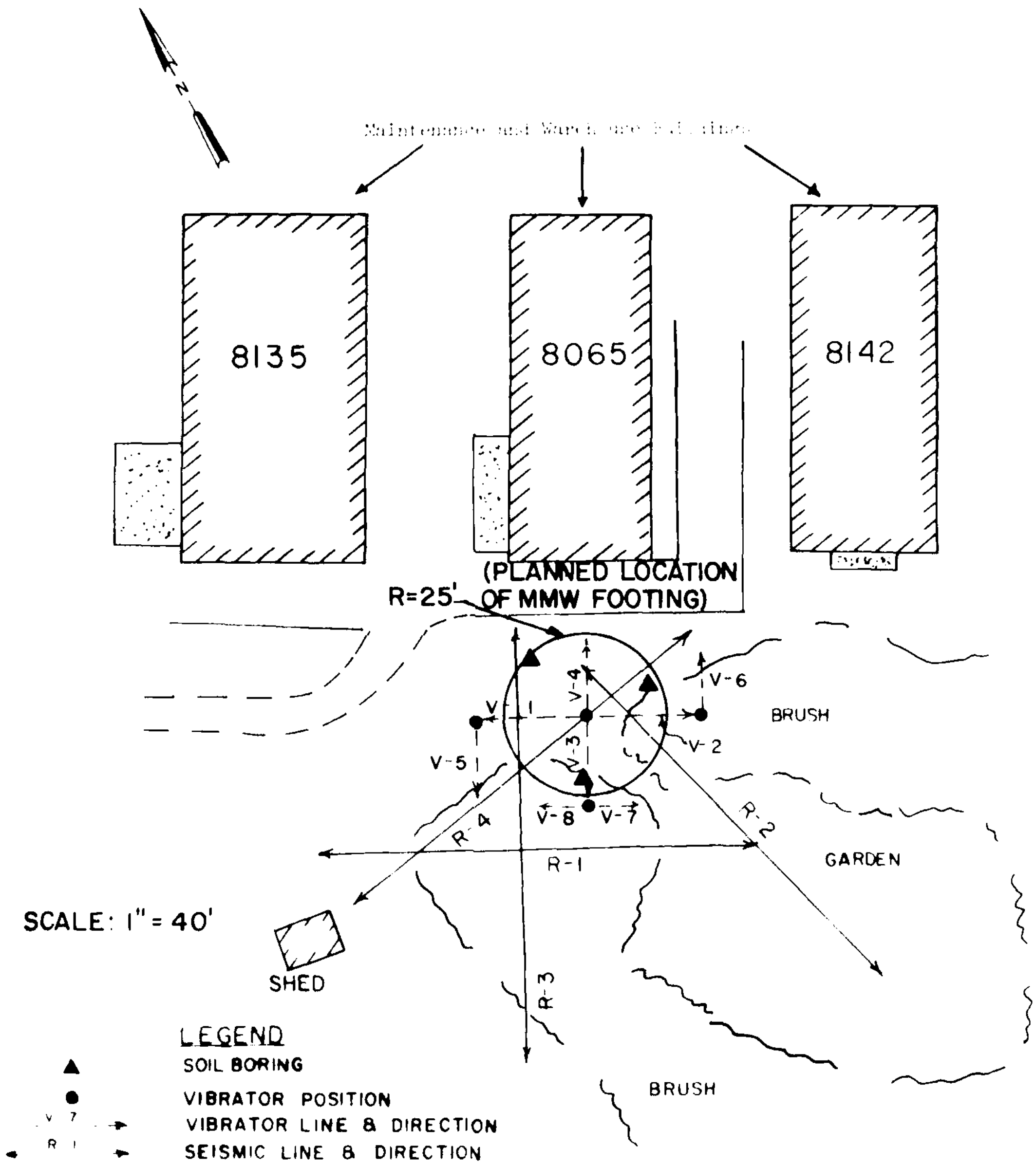

Figure 2. Seismic and vibratory test layout

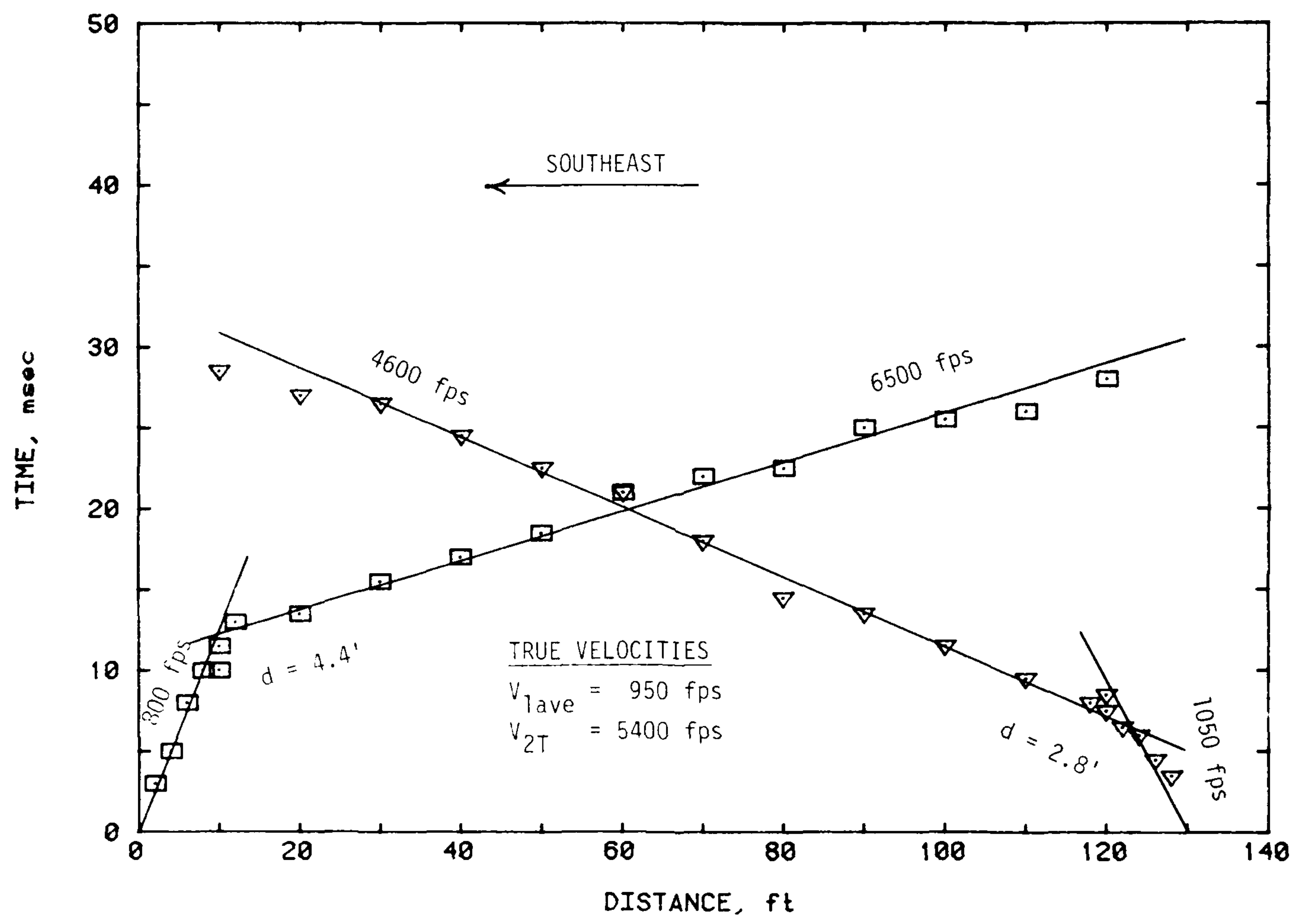

Figure [illegible]. Time versus distance plot for refraction line R-1

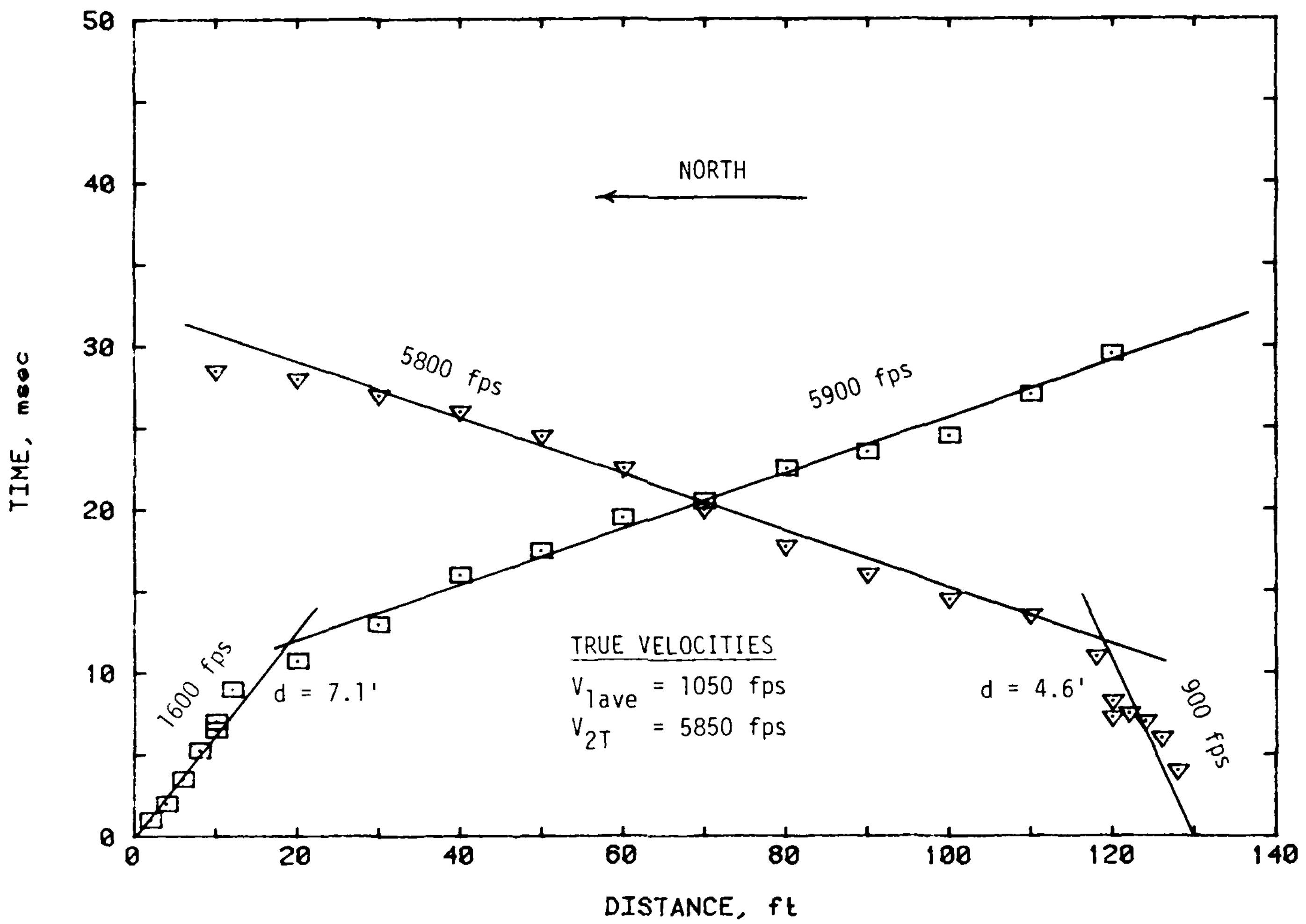

Figure 4. Time versus distance plot for refraction line R-2

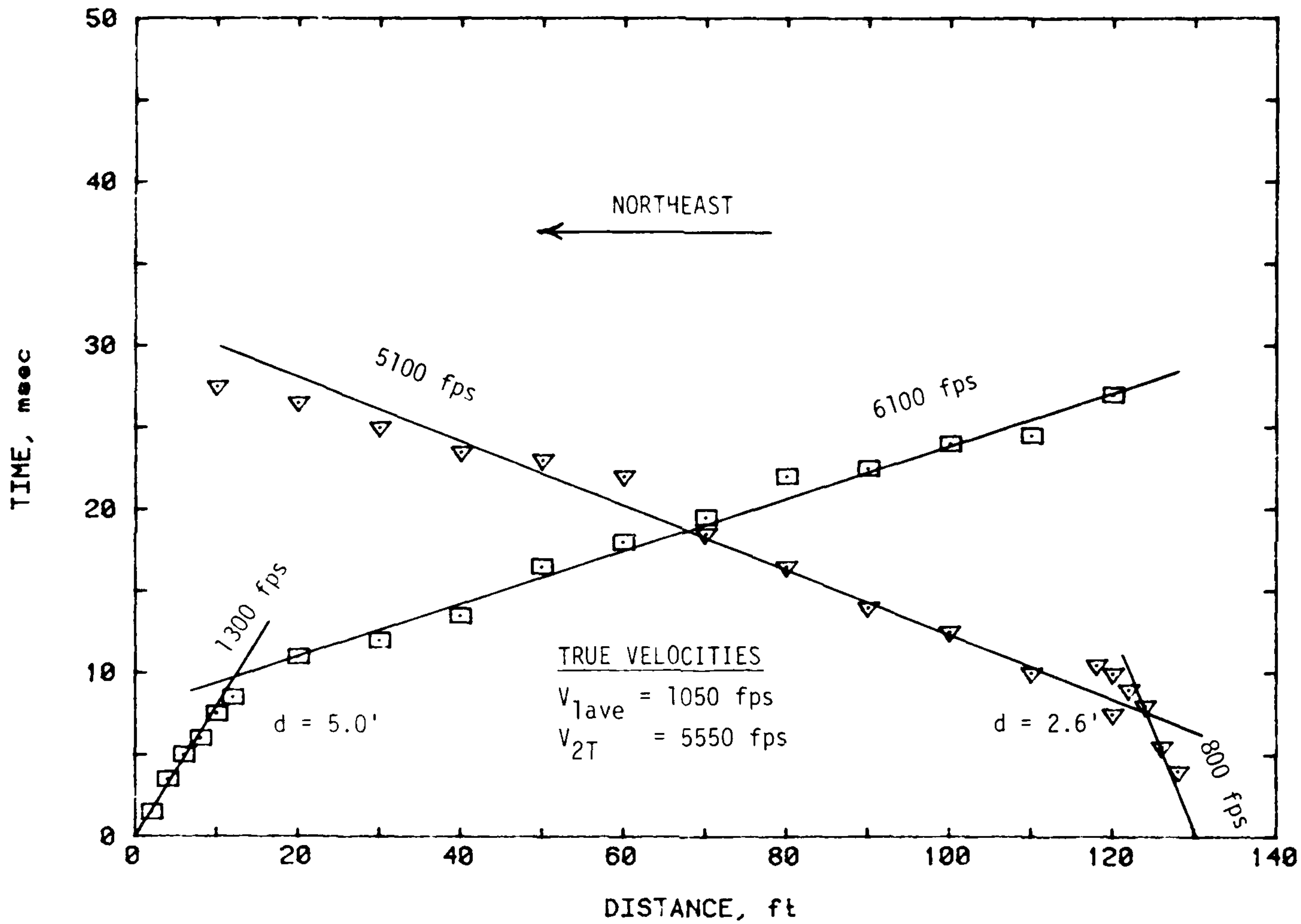

Figure 5. Time versus distance plot for refraction line R-3

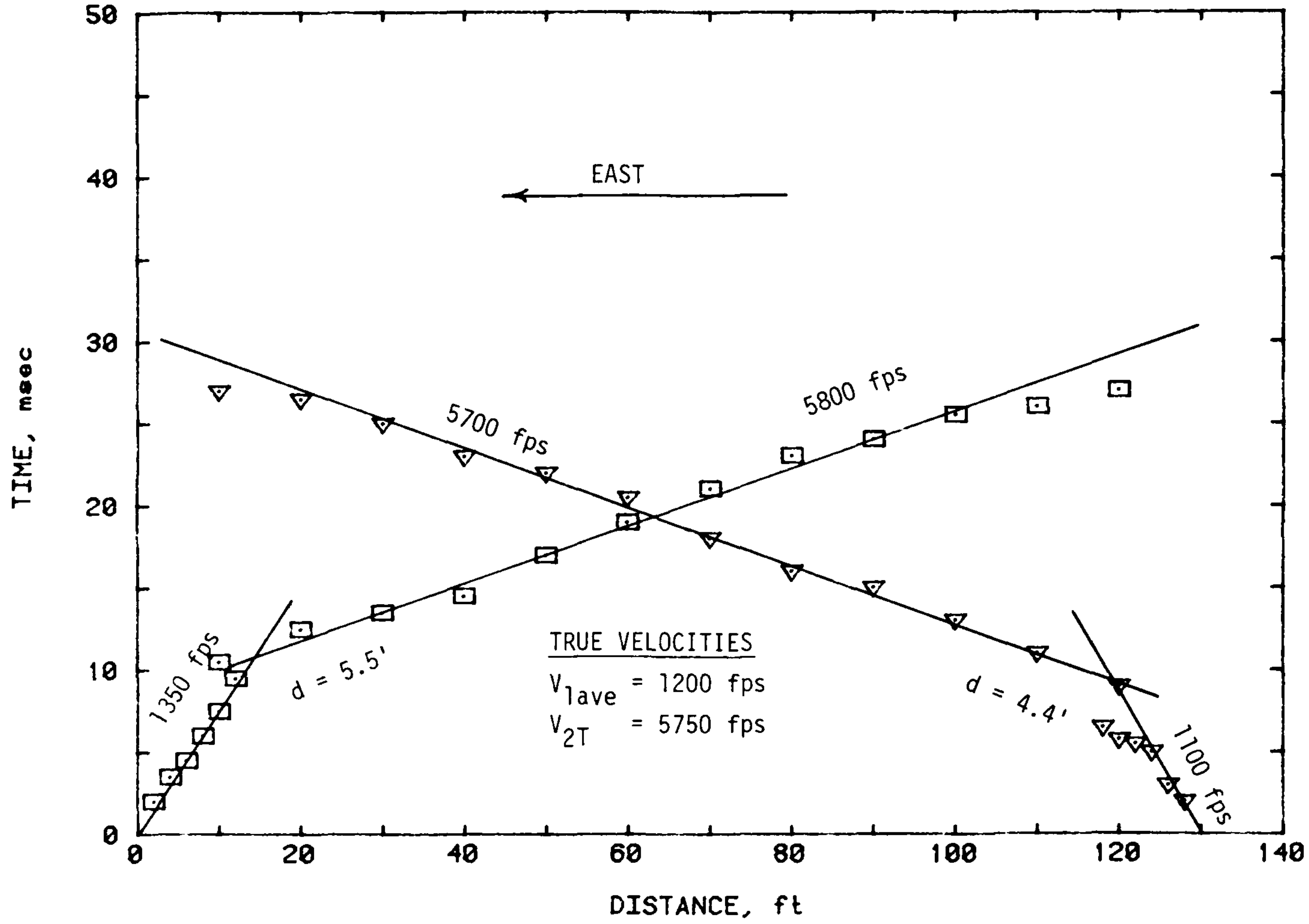

Figure 6. Time versus distance plot for refraction line R-4

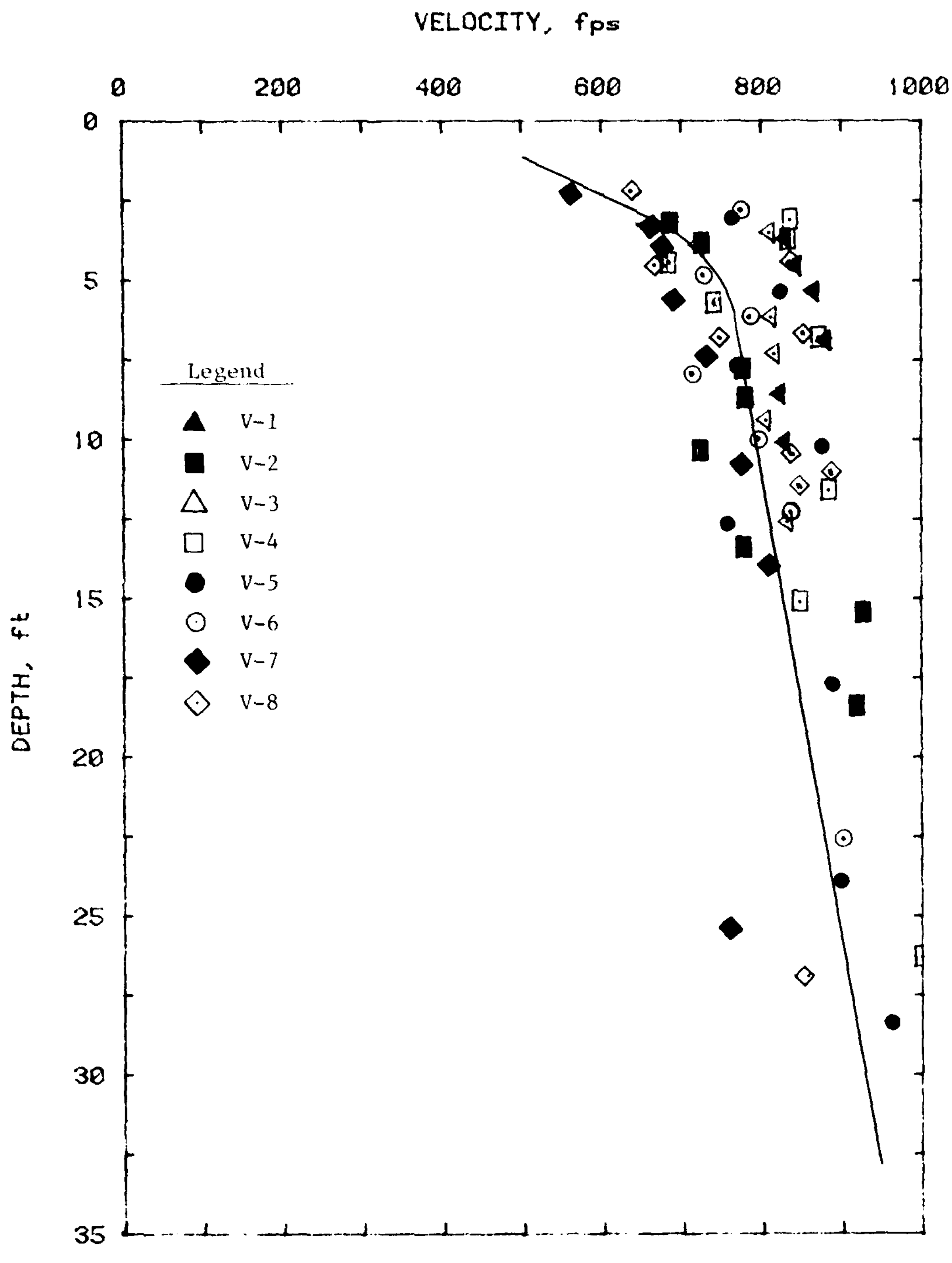

Figure 7. Shear wave velocity versus depth

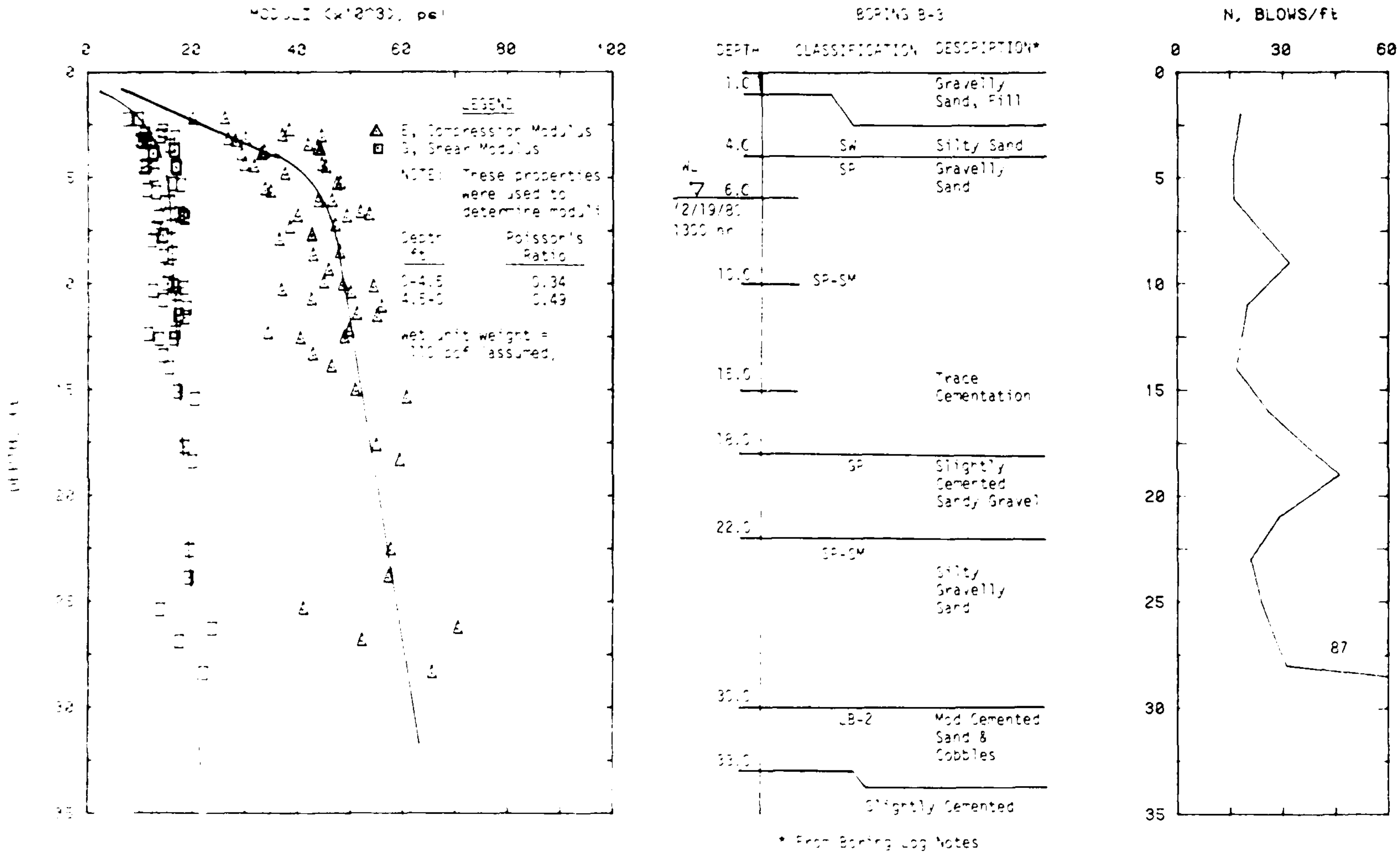

Figure [illegible]. Moduli, soil classification, and blow counts versus depth

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